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Division of Horticulture

Irrigation of Orchards by Sprinkling

by

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[1] In cooperation with the State Committee on the Relation of Electricity to Agriculture.
[2] In cooperation with the United States Department of Agriculture.
[3] On leave.

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IRRIGATION OF ORCHARDS BY SPRINKLING[1]

by

F. L. Overley, E. L. Overholser, H. L. Garver, S. C. Vandecaveye, A. Spuler,[2] O. M. Morris, C. P. Harley, E. L. Reeves, and H. C. Diehl

INTRODUCTION

One of the important production problems confronting the fruit grower in the irrigated sections of the state of Washington is how to make the most efficient use of the available irrigation water. The main purpose of any irrigation system is to wet the soil effectively and economically. Three different methods of irrigation are used: (1) Surface irrigation where the water is delivered over the ground generally by furrows or flooding; (2) sub-irrigation where the water is delivered to the root zone of the plants by some underground method; and (3) sprinkler irrigation where the water is delivered under pressure in pipes and is applied in the form of fine drops, spray, or mist through sprinkler heads or from perforated pipes.

The sprinkler system has been used for many years in the irrigation of lawns. More recently the system has been used by a few growers of deciduous fruits and also for truck crops in certain sections of the United States. A few growers of subtropical fruits in Florida and California have also employed the overhead sprinkler irrigation. (Wadsworth. 5). An occasional grower in the irrigated districts of Washington has used the sprinkler system of irrigation in the orchard with apparent success.

OBJECTS OF THE EXPERIMENT[3]

During the past several years the interest on the part of fruit growers in the sprinkler method of orchard irrigation has increased. This has resulted from impressions that the use of sprinklers conserved the water, gave a more uniform distribution of water, favored greater utilization of fertilizers, aided in the control of certain insects and diseases, and, by keeping the foliage clean of dust, improved the photosynthetic capacity of the leaves. In an attempt to determine the facts

[1] H. C. Diehl is responsible for the discussion of the effect of sprinkler irrigation on arsenical spray residue on apples. C. P. Harley and E. L. Reeves are responsible for the discussion on the relation of type of irrigation to apple and pear diseases.

[2] Deceased.

[3] The investigations on irrigation of orchards by sprinkling were made in the Wenatchee district with the cooperation of the County Commissioners of Chelan County and the Wenatchee Valley Traffic Association.

in the orchards of the irrigated regions of Washington, studies were made during two seasons of both overhead and of ground sprinklers. In these studies the factors considered were the following: (1) Best types of sprinkler heads; (2) operating characteristics; (3) water measurements; (4) equipment; (5) installation; (6) soil type; (7) amount of water necessary; (8) cover crops; (9) fruit and tree response; (10) orchard insects; (11) spray residue removal; and (12) orchard diseases.

TYPES OF SPRINKLERS

Sprinklers may be divided roughly into three classes: (1) Gear-driven; (2) reaction; and (3) stationary head.

Gear-Driven Sprinklers. Sprinklers of the gear-driven type are operated by some sort of water motor, a vaned wheel, a warped disk like a water meter, or by an impulse motor against which the jet is directed. Energy imparted to the motor by the moving water is transmitted to the head through a train of gears. An exception to these is a sprinkler which uses a deflector-spoon to impart the necessary rotational energy to the sprinkler head. (Fig. 1) Another exception is the sprinkler in which the motive power is furnished by means of a steel ball which travels around a track designed for it. At each revolution the ball strikes a pin or projection, driving the sprinkling nozzle a short distance ahead.

Gear-driven sprinklers usually throw large quantities of water over wide areas, often covering an area 100 feet or more in diameter. When

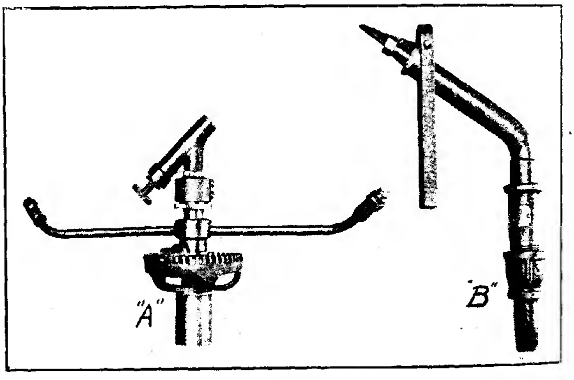

Figure 1. A, Gear-driven sprinkler; B, Deflector-spoon sprinkler.

used for irrigating orchards they are placed above the tops of the trees. They are equipped with two or more nozzles, one for throwing water long distances from the sprinkler and the others for covering the intervening space. Gear-driven sprinklers discharge relatively large amounts of water, from 10 to 20 gallons per minute, which is at the rate of approximately 0.12 to 0.24 acre inches per hour over the area covered.

The gear trains of power-operated sprinklers are usually enclosed in the head of the sprinkler. In some the water passes through the gears, while in others, the gears occupy a chamber from which the water is excluded, in which case they are packed with grease. Water passing directly over gears soon causes wear, particularly if sand or other abrasive materials are being carried by it.

Reaction Sprinklers. In reaction sprinklers, water is forced out through nozzles in the same manner as it is in the motor-driven sprinklers. The sprinkler head is equipped with two or more nozzles, but instead of a water motor and set of gears, the dynamic action of the water as it leaves the nozzle and passes through the air builds up a back pressure which reacts upon the nozzle, constantly pushing it backward, thus causing rotation of the sprinkler head.* (Fig. 2.)

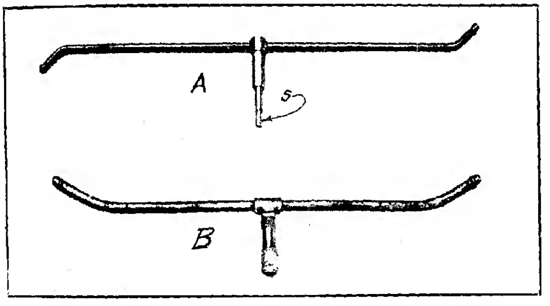

Figure 2. A, Reaction sprinkler showing strainer s. B, Sprinkler equipped with an ordinary pipe coupling for attaching to the riser.

The area covered by the reaction type of sprinkler is not generally as large as that covered by the gear type, nor is the action quite as positive. The speed of rotation is easily modified by changing the horizontal

*For a more complete discussion of the principle involved in the flow of water from jets, consult any good treatise on hydraulics.

angle of the nozzle with respect to the radius line through the nozzle and the center of rotation. If the height to which the water is thrown does not affect its application, the nozzle angle may be changed by turning the sprinkler arm in the sprinkler head as it is usually threaded and screwed in. If the arm is not screwed into the head or if the height to which the water is thrown does concern the operator, there remains only the bending of the arm. This should be done a little at a time until the proper angle is found, since the pipes of which these arms are made are not designed for much bending.

The reaction sprinkler is the most suitable of the three types for use under trees in orchards. Although the area of coverage is small as compared with the large gear-driven sprinklers, it may be had in models with sufficient coverage to reach the tree rows. The diameter of the area covered varies from 30 to 60 feet, depending upon the make of sprinkler and water pressure.

Stationary Head Sprinklers. The stationary head sprinkler includes those in which none of the moving parts carry water. The water may be driven through a number of small holes or it may be given a whirling motion by means of vanes and thrown through a larger hole in the form of fine spray or very small drops. These sprinklers cover only small areas and throw the water too high for use under fruit trees. Their chief application is in gardens and on lawns.

There is also a group of these so-called stationary head sprinklers with devices on the outside, which move when struck by the water,

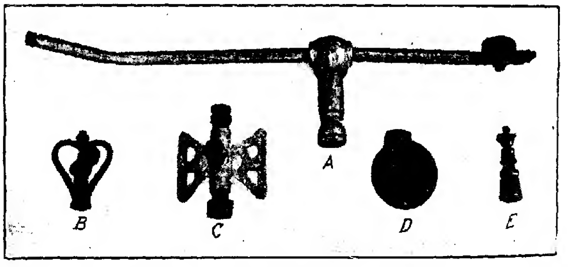

Figure 3. Common types of sprinklers. A, Reaction sprinkler. The chamber on the right arm contains an eccentric disk which imparts a vibration to the slowly rotating sprinkler. The vibration greatly reduces the friction. B, stationary head sprinkler with rotating lug that spreads the water. C and D, stationary head sprinklers suitable for lawns and gardens. E, stationary head sprinkler with a fluted cone which rotates as the water passes up over it, causing it to spread evenly over the wetted area.

and the water is thus spread more or less evenly over the area covered. This type of sprinkler usually has but one hole which is considerably larger than those of the other stationary head sprinklers. The large hole has a decided advantage in that it does not clog so readily with foreign material carried by the water. (Fig. 3.)

OPERATING CHARACTERISTICS OF SPRINKLERS

Sprinklers may differ in their operating characteristics as follows: (1) The amount of water they will handle; (2) the trajectory of the water; (3) the uniformity of coverage; and (4) the pressure required to operate them.

Capacities. The capacity of a sprinkler is a matter of design. It may be altered by replacing the nozzle with one of different size, but the nozzle may be changed to accommodate the sprinkler to different pressures. The capacities of sprinklers commonly found in Washington orchards vary from 2 to 10 G. P. M. (gallons per minute) for the reaction type, but for the gear-driven types the variation is from 10 to 20 G. P. M.

Trajectory. By the trajectory is meant the path taken by the water between the sprinkler and the ground. Some sprinklers throw the water high into the air, while others possess what is known as a

Figure 4. Sprinklers in operation in apple orchard. Note the relatively flat trajectory taken by the streams of water and the distance the water travels.

flat trajectory, that is, the water does not rise much above the level of the sprinklers. (Fig. 4.)

For orchard irrigation, particularly if ground sprinklers are used, a relatively flat trajectory is desired, provided the quantity of water discharged is kept low enough to prevent erosion. There are several reasons why a flat trajectory is better under the trees. When water is sprinkled on the foliage, much of the spray material is washed off, silt may be deposited, and disease, insect, and cleaning problems may become more complicated. Furthermore, driving of the water by the wind may be objectionable when the water is thrown more than three or four feet above the ground. When the lower branches of trees are loaded with fruit or the cover crop is high, the uniform distribution is difficult to accomplish with ground sprinklers regardless of the trajectory.

Uniformity of Coverage. The uniformity with which the ground is covered constitutes one of the important advantages of the sprinkler system of irrigation as compared to the rill or furrow system. In the selection of sprinklers it is, therefore, important to choose those which cover all parts of the wetted area about the same. There may be a tapering off near the outer part of the circle covered, since there will of necessity be some overlapping of areas by adjoining sprinklers. Figures 5 and 6 illustrate the amount of water applied to concentric areas on a plot by two commonly used sprinklers. That elevation makes very little difference in the distance a sprinkler will throw water is seen by examination of Figures 5 and 6. In Figure 5 the sprinkler was located 30 inches above the ground, while in Figure 6 the same sprinkler was placed 20 feet above the ground, the pressure being measured at the same distance above the ground in both cases.

Pressure. Water pressure is measured either in pounds per square inch or in feet head. A column of water one inch square and 2.3 feet high weighs approximately one pound. The total weight of water will, of course, depend upon the area covered, but the pressure per unit area depends only upon the height. For this reason the two terms may be used interchangeably. Pipe friction losses are usually referred to in feet head per hundred or thousand feet of pipe, but practice seems to dictate that pressures at sprinkler heads be measured in pounds per square inch.

The variations in pressure in the orchard will depend upon two factors: (1) elevation, and (2) pipe friction. The water may be assumed to enter a pipe 140 feet above the lower side of the orchard. After the pipe is filled and the valve closed so that no water is allowed to flow through, a gauge attached at the lowest point should read about 61 pounds. If the upper side of the orchard is 35 feet

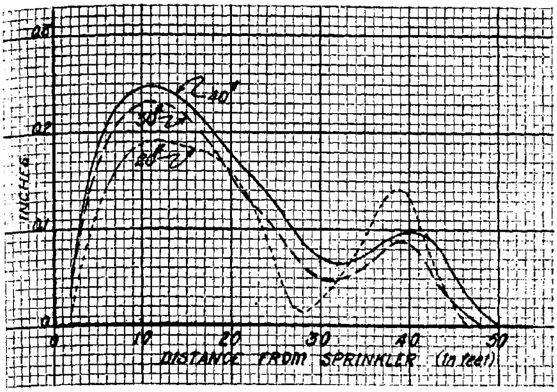

Figure 5. Chart showing uneven spread of water from an orchard sprinkler, Placed 30 inches above ground.

higher than the lower side, what should the pressure be at the upper side? Since the pressure of 35 feet of water is slightly over 15 pounds, the gauge should read the difference between 61 and 15, which is 46. It will make no difference whether the pipes are vertical or follow the contour of the land, the static head (water standing) will be the same in both cases if the elevation of the inlets is the same. This is not true if the water is moving, as will be noted in the discussion of pipe friction.

Sprinklers employed in the ordinary irrigation systems are usually designed for operating pressures ranging between 20 and 40 pounds per square inch. Many of them require special nozzles for given pressures, and should be changed when the pressure is changed. As the area covered decreases or the coverage becomes uneven, it is desirable to change to a nozzle designed for the new pressure. This change is not necessary in order to adjust for the ordinary fluctuations of pressure that may take place from hour to hour or even from day to day, but it may be worthwhile to equip sprinklers on one side of the orchard with one type of nozzle and those on the other side with another, if the pressure is not uniform over the entire orchard.

The distance that a sprinkler will throw water is not wholly dependent upon the pressure applied, provided the pressure is reasonably close to that for which the sprinkler and nozzle were designed.

A sprinkler designed to operate at 35 pounds pressure will throw water approximately the same distance at 30 or 40 pounds as at 35, but may fall short if the pressure should drop to 20 pounds. (Figs. 5 and 6.)

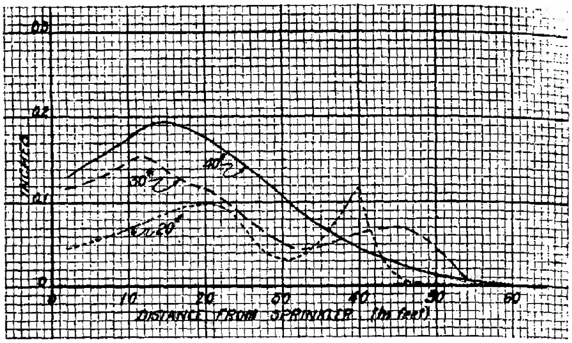

Figure 6. Chart showing uneven spread of water from an orchard sprinkler, placed 20 feet above ground.

The quantity of water discharged from the orifice of a sprinkler is not in direct proportion to the pressure. There is a fairly definite minimum pressure at which any given sprinkler will discharge its maximum quantity of water. Below this minimum pressure the quantity diminishes, but above it the effect is not an increased discharge but a greater degree of atomization. It is, therefore, readily seen that there is an optimum pressure for any given sprinkler when fitted with a given nozzle, and that nothing is gained by using pressures higher than this value. The pressures referred to are those at the sprinkler heads and not at the foot of a tall riser or at some distant point along the pipe line.

Pipe Friction. Pressure losses may be due to the resistance to flow as a result of pipe friction, or the piping system may contain leaks. Either one of these may be the cause of unnecessarily large bills for power or of reduced efficiency of sprinklers. When water flows through a pipe, there is a certain resistance to its motion. This is caused in part by the rubbing friction between the water and the pipe surface, and in part by internal resistances within the water itself resulting from disturbances incident to the flow. The resistance is a result of the combined action of these two factors, and is known

as friction. The loss of pressure, or head, because of resistance in a straight pipe with uniform flow, is called "friction head."

Friction head may be defined as the number of feet the inlet of a given length of pipe (usually 100 feet or 1000 feet) must be above the outlet to cause a given quantity of water to flow through when the lower end is discharging into the air, or, if submerged, when the head above the outlet is the same as the head above the inlet. Table 1 gives values for several sizes of pipe with various quantities of water flowing. An example will serve to explain both the definition and the use of the table. With a flow of 30 gallons of water per minute through a 1¼ inch pipe, the value given is 23.5 feet. This means that in order to cause 30 gallons of water per minute to flow through 100 feet of this pipe the point of entrance must be 23.5 feet higher than the outlet.

In the foregoing discussion it is assumed that the water flows through the pipe as a result of the action of gravity. In many installations the water must be forced through the pipes by means of pumps rather than by the force of gravity. The pump will, therefore, be required to develop a pressure equal to a column of water 23.5 feet high,

Table 1. Friction Head in Iron Pipe*

Discharge in gallons per minute	Diameter of Pipe in Inches									
	¾	1	1¼	1½	2	2½	3	4	5	6
	Friction loss in feet for each 100 feet of pipe									
3	4.1	1.26								
4	7.0	2.14	0.57	0.26						
5	10.5	3.25	0.84	0.40						
6	14.7	4.55	1.20	0.56	0.20					
8	25.0	7.8	2.03	0.95	0.33					
10	38.0	11.7	3.05	1.43	0.50					
15	80.0	26.0	6.6	3.1	1.1					
20		42.0	11.1	5.2	1.82	0.61	0.25			
30			23.5	11.0	3.84	1.29	0.54			
40				18.8	6.6	2.2	0.91	0.22		
50				28.8	9.9	3.32	1.38	0.34	0.11	
60					13.9	4.65	1.92	0.47	0.16	
70					18.4	6.2	2.57	0.63	0.21	
80					23.7	7.9	3.28	0.81	0.27	
90						9.8	4.08	1.00	0.34	
100						12.0	4.96	1.22	0.41	
150						25.5	10.5	2.62	0.88	
200							17.8	4.40	1.48	0.61

* Hydraulic Tables, Williams and Hazen, New York. 1909. Coefficient here used is 100, a fair value where the interior of iron pipe is roughened by 10 to 15 years' rust formation.

or about 10 pounds, if it is to maintain the flow of 30 gallons per minute through 100 feet of 1¼ inch straight, horizontal pipe. Friction head is added to the static head, if water is being raised when calculations are being made for a pump installation, but if the water flows by gravity the friction head must be subtracted.

Wood pipe has a lower resistance to the flow of water than iron pipe. It frequently costs less than iron pipe in sizes above 3 inches. It should be used where it may be buried. Figure 7 shows the loss of head due to friction in water flowing through wood pipe.

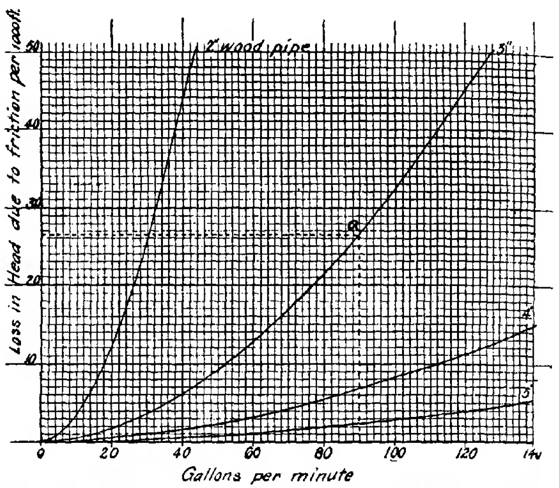

Figure 7. Chart showing loss in head (in feet) due to resistance to the flow of placed 30 inches above ground.

Evaporation from Sprinklers

A few tests were made at the Irrigation Branch Experiment Station located at Prosser, Washington, to determine, if possible, the amount of water evaporated between the sprinkler and the ground. Among the contributing factors that determine the rate of evaporation are wind, relative humidity, and temperatures of air and water. Of these, perhaps wind has the greatest influence. Preliminary data showed that the percentage of water lost from sprinklers that broke the water into a fine mist was apparently little greater than from sprinklers that distributed water in large drops. The small droplets

from sprinklers are much more easily carried away by the wind, however, than are large drops.

Water Measurements[1]

Whether irrigation is by means of sprinklers or by the furrow method, it is essential that some sort of measurement be made of the quantity of water applied. There are various methods and also many units for the measurement of water. Perhaps the most common of the methods used in the irrigated sections of Washington is by means of the weir boxes, or by orifices submerged under some given head of water. These methods are not adapted to the measurement of water within closed conduits, but they may be used at the inlet.

The three common methods of measuring water in pipes are Pitot tubes, Venturi meters, and integrating water meters. The first two of these merely indicate the rate of flow and the third registers the amount. Most irrigation systems carry enough abrasive material to ruin ordinary water meters in a season or two. Therefore, water meters are not recommended except for plot studies. The simplest way to determine the quantity of water is to assume the weir setting as correct, attach just enough sprinklers to use all of the water allotted, and shift the position of the sprinklers as soon as sufficient time has elapsed for applying the desired quantity.

Since there are several units used for measuring water, some method of comparison may be of value. One of the common units used is the miner's inch. This unit has no legal definition in the state of Washington and should be used for rough estimates only. The rate of flow of water in a miner's inch varies from 9 to 12 gallons per minute, depending upon the way it is defined in different communities. Many growers have available one-half miner's inch of water per acre for their orchards. In the better types of orchard soils with an average cover crop, this is sufficient water for high fruit production, provided it is applied uniformly to the soil, without allowing for loss of water from irrigation ditches or by leaching below the root zone of the trees.

Miner's Inch. One miner's inch of water equals 11.22 gallons per minute discharged through each square inch of an opening two inches high in a plank 1¼ inches thick, under a head of 6 inches to the center of the opening. One-half miner's inch per acre, the amount commonly used, is equal to 5.61 gallons per minute or 336.60 gallons per hour, or 8078.4 gallons per day. One-half miner's inch equals one acre inch of water if allowed to run 3.36 days. At this rate of application, from May 1 to September 1, water running continuously would equal 36.6 inches of water to each acre of soil.

[1] Wright, C. C., Units of Measurement and the Application of Irrigation Water. Washington Agr. Exp. Sta. Bul. 145. 1929.

Table 2. Number Gallons of Water per Tree per Acre Inch of Irrigation Water

Trees per acre	Tree spacing	Gallons per tree per acre inch
21	45.2 x 45.2	1293.1
24	42.4 x 42.4	1131.4
27	40.0 x 40.0	1005.7
28	39.7 x 39.7	969.8
32	36.7 x 36.7	848.6
34	36.0 x 36.0	798.6
35	35.3 x 35.3	775.8
37	36.0 x 32.0	733.9
38	33.9 x 33.9	714.6
40	36.0 x 30.0	678.8
43	32.0 x 32.0	631.5
45	31.1 x 31.1	603.4
45	32.0 x 30.0	603.4
48	30.0 x 30.0	565.7
48	36.0 x 25.0	565.7
48	32.0 x 28.0	565.7
52	30.0 x 28.0	522.2
54	28.2 x 28.2	502.8
54	32.0 x 25.0	502.8
56	28.0 x 28.0	484.9
56	30.0 x 26.0	484.9
58	30.0 x 25.0	468.2
64	26.0 x 26.0	424.3
67	25.4 x 25.4	405.3
67	18.0 x 36.0	405.3
70	25.0 x 25.0	387.9
75	18.0 x 32.0	362.0
76	24.0 x 24.0	357.3
80	18.0 x 30.0	339.4
85	16.0 x 32.0	319.5
85	22.5 x 22.5	319.5
90	22.0 x 22.0	301.7
91	16.0 x 30.0	298.4
91	15.0 x 32.0	298.4
96	21.2 x 21.2	282.8
96	15.0 x 30.0	282.8
97	18.0 x 25.0	279.9
97	16.0 x 28.0	279.9

(Continued on next page)

Table 2 (Cont.)

Trees per acre	Tree spacing	Gallons per tree per acre inch
104	15.0 x 28.0	261.1
108	20.0 x 20.0	251.4
112	15.0 x 26.0	242.4
116	15.0 x 25.0	234.1
134	18.0 x 18.0	202.6
170	16.0 x 16.0	159.7
173	15.0 x 15.0	140.7

Cubic Feet per Second. Occasionally water is measured in cubic feet per second (C. F. S.). To convert this value to gallons per minute, the unit usually used in connection with sprinklers and pumps, multiply C. F. S. by 450.

Acre Inches. Another unit frequently used is "acre inches." An acre inch is the amount of water required to cover one acre to a uniform depth of one inch. One acre inch contains 27,154 U. S. gallons.

Table 2 gives the gallons of water allowed per tree with a varying number of trees per acre when one acre inch of water is applied per acre per season. From this table the number of gallons to be applied per tree at each irrigation for any planting distance can be obtained for any desired annual application in acre inches.

EQUIPMENT

The equipment required for sprinkler systems of irrigation will vary with each installation. Where the intake to the system is high enough above the area to be sprinkled to furnish the required pressure by gravity, all that is required are the pipe and sprinklers. In many orchards, however, it will be necessary either to furnish all of the pressure by means of a pump or a pump may be required to boost the pressure.

Piping. The material used in piping the orchard need not be of the same high quality as that used in the stationary spray system. It is frequently economical to use well casing or boiler tubing. The joints may be welded, thus eliminating many fittings required with screw joints. Wood pipe may also be used in the sprinkling system, where there is no necessity of moving it. It may be used to good advantage if the mains consist of long runs where few lateral connections are required.

Pump. Centrifugal pumps are probably the most satisfactory for use in sprinkler irrigation systems. They have fewer wearing parts and are not rendered unserviceable by abrasive material as quickly as other kinds of pumps. There are no valves which get out of order or under which floating material may lodge. They may be connected directly to an electric motor of standard 1800 or 3600 R. P. M. Centrifugal pumps for operating at lower speeds may also be obtained, but these are usually designed for larger capacity than is commonly used on sprinkler systems. Pumps should be purchased for the required pressure and volume.

Settling Box. In nearly every installation where water is taken from irrigation canals, it will be necessary to use some kind of settling box to get rid of sand or other abrasive material that may be carried by the water. The box should be large enough to give the heavier-than-water matter time to settle out and the light material time to rise to the surface. Since an open tank large enough to allow sufficient time to get rid of the foreign matter is too expensive, a tank using a system of baffles and screens is frequently substituted. A small box of this kind is shown in Figure 8.

Sprinklers. Several factors enter into the selection of sprinklers for orchard irrigation. Among the most important are: The rate at which they deliver water, and the path of the stream. Each kind of soil has its own optimum rate of absorbing moisture. The contour of the land has its influence on the rate at which water may be applied and the method of applying it. The amount of water available may in some cases be a factor. The kind and spacing of trees will in a large measure determine the capacity and range of the sprinkler. On steep hillsides water applied rapidly may cause washing. Sprinklers which distribute water very slowly should be used on clay soils and steep hillsides.

The sprinkler should be of a type that may be located near the ground. It must throw the water uniformly over an area large enough to permit a convenient arrangement of pipes. It must throw the water with a comparatively flat trajectory. Where booster equipment is necessary, the sprinkler should require a low minimum pressure.

Installation

A definite plan of the entire system should be made previous to the installation. It may not be necessary to install all of the system at one time, but it should be so planned that there will be no necessity for rebuilding each time additions are made.

There are two general types of systems in use. One is a system in which part or all may be moved about the orchard. In some instances the main pipe lines are laid in a permanent place. The laterals

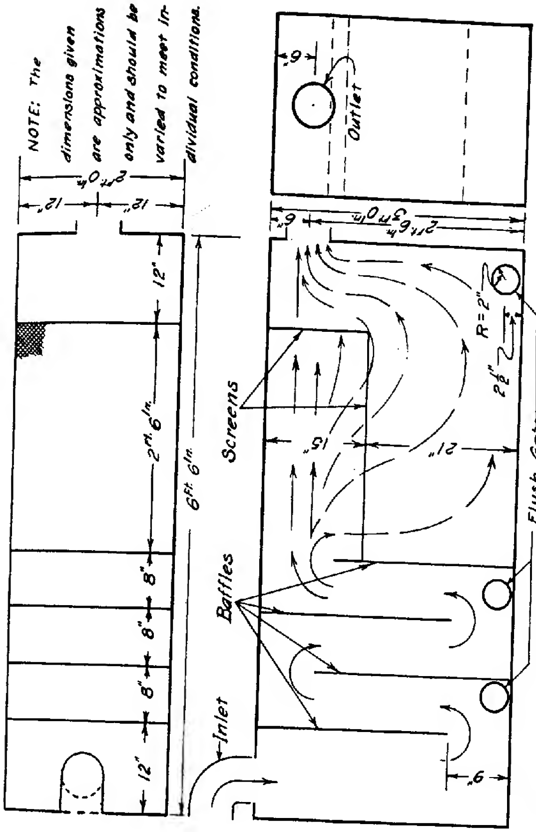

Figure 8. Tank for removing floating debris from irrigating water. (This tank has been used for two years in experimental orchard at Wenatchee.)

which carry the water to the sprinklers are moved from one location to the next. These laterals may be hose or pipe. Occasionally several small sprinklers are attached to a piece of pipe and are moved about as a unit. This unit is attached to the main by means of a hose. In some installations the laterals are permanently located, and the sprinklers moved, while in others the laterals are dissembled and moved to

the next position. With other systems, all of the equipment is permanently located and the pipes may be buried.

No one method of piping may be considered as best for all orchards. There should be plenty of mains, or headers, so that it will not be necessary to use long laterals. The laterals feed directly into the sprinklers and will deliver water to them at a much more uniform pressure if their number is kept low.

The pipe may be graduated as to size. As the volume of water diminishes, the size of the pipe may be diminished. The rate at which the size of pipe may be reduced will depend upon the kind and number of sprinklers used.

More pipe is required for the low, or ground sprinklers than for sprinklers that operate above the tops of the trees. The ground sprinklers have a very decided advantage over the overhead, however, when it becomes necessary to remove them from the standpipe for cleaning or moving. Pressure for operating the ground sprinklers may be somewhat less than for overhead sprinklers.

A sprinkler that covers a square area has recently been placed on the market. If this type of sprinkler can be made to meet the requirements of sprinklers as set forth in this bulletin, it should simplify the piping systems in many orchards.

Use of the Spray System. It is doubtful if the pump of the stationary spray plant would be satisfactory for pumping irrigation water, since it is designed for pumping comparatively small quantities of liquids against high pressures. All of its working parts must be kept in excellent condition. Sand and other abrasive materials must be kept out of spray pumps, as they soon ruin the valve seats and cylinder walls.

It is frequently convenient, however, to use part of the spray plant piping system. Several orchardists in Washington have found the use of part of the spray system satisfactory for carrying irrigation water. Where the spray line crosses the irrigation line at the desired location of a sprinkler system lateral, a connection may be made as shown in Figure 9.

Ordinarily spray system pipes are small and offer considerable resistance to the flow of water. These pipes should be small because of the desirability of keeping the spray mixtures moving rapidly. The pressure lost as a result of friction may be small when compared with the total pressure delivered by the spray pump, but when the large quantities of irrigation water pass through, the pressure drop is excessive.

Costs. The installation cost of a sprinkler system depends upon its elaborateness. A completely equipped permanent sprinkler system installed cost between $300.00 and $350.00 per acre in the Yakima and

Wenatchee valleys in 1930. By using light welded steel tubing and movable sprinklers the cost has been kept as low as $40.00 per acre. This low figure was obtained in an orchard where pumping equipment was not required. The costs given are probably the extremes, with the actual cost of installation somewhere between these two values.

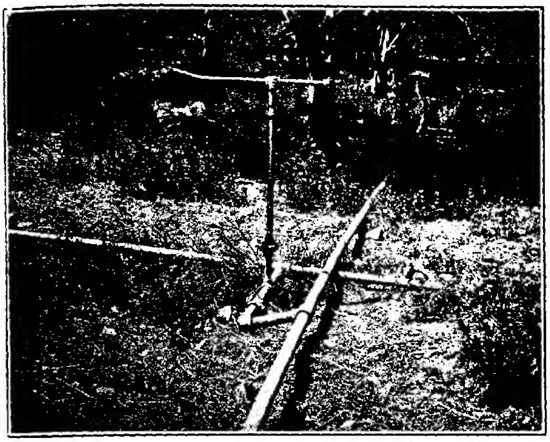

Figure 9. Method of connecting irrigation and spray systems where the spray lateral is to be used for sprinklers. Note that two valves are usually required, regardless of the position of the sprinkler on the connecting pipe.

Another item of cost is that of operation. This also varies with the type of installation and the number of difficulties encountered. If only enough sprinklers are used to cover a small area and these are moved frequently, the cost of operating may be high. Power for pumping will cost in proportion to the amount of water pumped and the pressure the pump is required to deliver.

RELATION OF SOIL TYPE

Soils can retain only a certain amount of water. When more water is applied than the soil can hold, even when applied slowly, it will move downward by gravitational forces. After reaching a depth beyond which plant roots penetrate, this water is essentially lost for plant use because the upward movement of water in soils moistened

at normal field capacity is very slow and only a small amount of this water, if any, is capable of upward or lateral movement by the so-called capillary forces. A considerable upward movement of water in soils is possible only when a constant water table is present in the subsoil. In such cases, roots of plants may derive their water supply from so-called subirrigation. The ideal method of applying water is to fill the soil to normal field capacity to the depth at which the roots feed and no deeper. This depth may be estimated roughly at six to eight feet in the better types of the orchard soils. Since the water-holding capacity of different soil types varies widely, depending upon the coarseness of the soil particles, or, in other words, upon the texture of the soil, it is evident that much more water is required to wet a clay loam soil six feet deep than is necessary to wet a coarse, sandy soil six feet deep. Keeping in mind the fact that the clay loam soil will absorb water much more slowly than the coarse, sandy soil, it is also obvious that the time required to wet the clay loam to a depth of six feet will be much longer than that required to wet the coarse, sandy soil to the same depth. Thus, the rate of application and time required for one irrigation are two important factors which must of necessity vary greatly with soil type.

A coarse, sandy soil, which may hold only 10 to 12 per cent moisture, contains a much smaller total amount of water in the feeding area of the roots than a clay loam soil, which may hold from 25 to 30 per cent moisture. The result is that more frequent sprinklings and sprinklings at a higher rate of delivery and of much shorter duration are necessary for coarse, sandy soils than for clay loam soils.

The sprinkling method of irrigation may be beneficial in at least two respects. **First,** it represents as nearly as possible the natural wetting of soil by rainfall, which means that a large part of the salts that often accumulate on the surface of furrow-irrigated soils should be kept down by proper sprinklings. This treatment may prevent the formation of certain types of impervious plow soles frequently found in furrow-irrigated soils, and may have a tendency to break up some of the hardpans that have been formed as a result of irrigation practices, thereby improving the structure of the soil. Evidence obtained in fields where the sprinkling irrigation system has been in use for several years supports this statement. **Second,** the sprinkler makes it possible to apply water more uniformly over the entire field, regardless of hillsides or steep slopes, thus preventing local seepage areas and local dry spots. These seepage areas are ideal places for the formation of alkali soils, and the physical condition of alkali soils is usually undesirable. Since in most cases the physical condition of soils does not change suddenly but takes place gradually as a result of changing practices, the experiments with the sprinkler system of irrigation on the soil under investigation have not been carried on long

enough to show marked changes in its physical condition, and the results necessarily must be interpreted to a certain degree from the analysis of basic factors known to be in operation in soils.

On soils of coarse texture and on steep hill slopes it is possible with the better installation to make a more uniform distribution of water by means of the sprinkler system of irrigation than by means of the furrow system. The transformation of plant nutrients from unavailable to available forms is the result of microbiological and chemical actions both of which take place extensively only in the presence of moisture. It is not difficult to find dry ridges between irrigation furrows of coarse-textured soils. The organic matter and mineral plant nutrients in these dry areas are not undergoing normal transformation, and, as a result, little or no available plant nutrients are liberated in these areas. Therefore, only a portion of the plant food materials in the form of commercial fertilizers and cover crops can be used by the crops growing on these soils. Perhaps the first and most striking advantage of the sprinkler system of irrigation is that it distributes moisture uniformly in coarse-textured soils and on steep hill slopes where uniform distribution of moisture by furrow irrigation is often very difficult. By making this uniform distribution of moisture in the entire feeding area of the soil, the micro-organisms are able to function throughout, and, consequently, better soil fertility is maintained.

A very important and necessary feature in maintaining a porous, mulchy structure and a desirable physical condition of soils under the sprinkler system of irrigation is the regulation and control of the rate of application of water to an amount never exceeding the maximum absorption capacity of the soil, and preferably somewhat below this capacity. The rate of absorption varies with every soil type and even within the same soil type if the previous soil management has resulted in marked differences in organic matter content. Water may be applied much faster on a coarse, sandy loam than on a silt loam or clay loam soil and still result in similar effects upon the physical condition of these various soils.

When sprinkler water is applied faster than the soil can readily absorb it, some of the excess water will accumulate in small pools on the surface, causing a running together or a certain degree of puddling of the soil and also often resulting in a run-off or washing of the soil. The sprinkling method of irrigation has been discontinued in some orchards because of the running together and hardening of the surface soil. This condition can be overcome by growing a good cover crop, which will allow an accumulation of plant residue on the surface soil, or by reducing the output from the sprinkler head. On the other hand, when furrow irrigation water is applied faster than the soil can absorb, a run-off occurs but usually no serious puddling of the

soil takes place. Thus the physical condition of the soil may be affected adversely by sprinkling irrigation, if the rate of application of water is greater than the soil can readily absorb.

EXPERIMENTAL PLOTS

The sprinkler experiments were made on a good producing Jonathan orchard about 22 years of age located in the Wenatchee district. The trees are spaced 40 by 40 feet apart with fillers, about 54 trees to the acre. The yield per acre for 1929-30-31 averaged approximately 1000 packed boxes. The ground was covered with an average cover crop—some alfalfa but mostly weeds. The soil is classified by Kocher, U. S. Bureau of Soils (2), as Cashmere, gravelly, coarse, sandy loam. It is characterized as follows: "The surface soil of the Cashmere, gravelly, coarse, sandy loam consists of about 12 inches of brown to grayish-brown or dull, brown, coarse, sandy loam containing a large percentage of angular or sub-angular rock fragments from 2 to 6 inches in diameter. The subsoil is a light brown to grayish-brown, gravelly, sandy, loam of medium to coarse texture, underlain at depths varying from 3 to 5 feet by a mass of partly rounded gravel, cobbles, and coarse sand . . . . Owing to the porous, leachy structure, the soil dries out quickly and underdrainage is excessive."

Amount of Water Necessary for Irrigation*

A wide variation of opinion exists regarding the amount of water necessary to apply to the soil during an irrigation season. Several factors, however, such as cover crops, slope of ground, type and depth of soil, evaporation, tree spacing, age of trees, and others have a marked influence on the amount of water needed for an individual orchard. Many of the successful orchards in Washington are located on sloping ground where the soils are more or less uneven in depth and texture. The observations and experimental data for the sprinkler method of irrigation for the years 1930 and 1931 indicate that 30 to 36 acre inches of water properly applied without waste are sufficient to keep the main root zone of the soil supplied with moisture during the growing season. Additional water is necessary, however, to restock the lower areas in deeper soils during the fall, winter, or spring, either by natural rainfall or by early spring or late fall irrigation. Furrow and flooding types of irrigation are tedious and wasteful on steep and rolling ground and on coarse, sandy, open soils, while the sprinkler type of irrigation is especially effective under these conditions.

Six sets of soil samples for each plot were taken before and after each irrigation, three to 10 feet from the tree, for each foot of soil

* C. C. Wright, Specialist in Irrigation Investigations of Western Irrigation Agriculture of the U. S. Dept. of Agriculture, formerly located at the Irrigation Branch Station at Prosser, Wash., cooperated with the 1930 studies comparing sprinkler and furrow systems of irrigation on water penetration.

layer to a depth of six feet, in 1930. Three similar sets of samples were taken for each plot, 10 feet from the tree, in 1931, except in special plots where the samples were taken three, six, and 10 feet from the tree. Each foot layer was sampled separately, and the average determined later. The per cent moisture was computed on a dry soil basis.

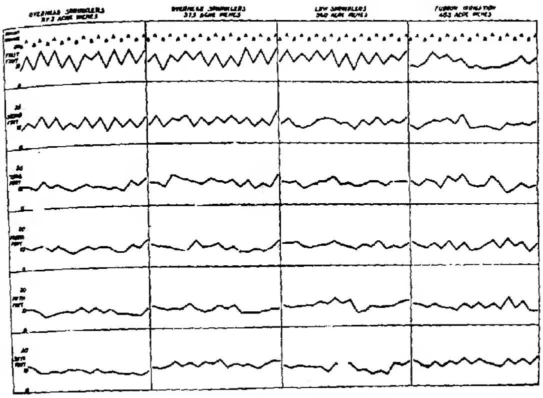

Figure 10. Chart showing the percentage of moisture before (B) and after (A) each irrigation at from 1 to 6 feet, with overhead and ground sprinklers and with furrow irrigation.

Figures 10 to 12 show the general soil moisture content at different depths before and after each irrigation of varying amounts of water, applied by the overhead and ground sprinklers, and the furrow method. Occasionally some of the soil moisture determinations indicated more moisture before irrigation than after irrigation. These apparent discrepancies resulted from variation in the soil texture, since it was impossible to take the soil samples at exactly the same spot each time. The soil profile showed no uniformity in texture at the same depth. The soil moisture in the upper three feet of soil was affected more by sprinklers than by the furrow irrigation. With the sprinklers, the entire surface soil was wet at each irrigation, while with furrow irrigation, often many areas of the surface soil between furrows were dry throughout the season. In all plots studied, however, the average percentage of moisture in the upper three feet remained well above the danger zone or wilting point for the soil type. The wilting

point of the soil in the experimental orchard is approximately four per cent of moisture.

Figure 10 shows that the total acre inches of water applied during the growing season to one overhead sprinkler plot was 27.3 and to the other was 37.3 acre inches. Comparing the per cent moisture for the two plots in the first and second foot of soil, little difference is noted. From the third to the sixth foot, however, the plot with only 27.3 acre inches of water applied showed an average lower per cent of moisture throughout the season.

The low or ground sprinkler plots (Fig. 10) received 36 acre inches of water during the season, or practically the same as one of the overhead sprinkler plots receiving the larger amount of water. The per cent moisture in the soil for both plots receiving comparable amounts of water was about the same for the different levels from one to five feet inclusive. The ground sprinkler plot, however, showed slightly less moisture in the sixth foot, but this condition resulted from a more gravelly type of soil at that depth.

The furrow-irrigated plots (Fig. 10) received over 10 inches more water than that applied to any of the sprinkler plots. They were watered by five furrows between tree rows, about four inches in depth and about three feet apart. During the first half of the season the moisture content of the soil in the upper two feet in the furrow-irrigated plots was about the same as that in the sprinkler plots, but during the latter half, or drying portion, of the growing season, the per cent moisture in the first three feet was less than in the sprinkler plots. However, more water penetrated to the lower levels with furrow irrigation than with sprinkler irrigation. Under some conditions this moisture in the lower levels may have been lost as far as utilization by the tree is concerned.

The soil moisture studies carried on during the season 1931 (Fig. 11) represent four plots irrigated with ground sprinklers. Varying amounts of water from May 1 to September 1 were applied as follows: (1) "Lightly watered" plot 21.7; (2) "light-medium watered" or control plot 25.9; (3) "medium-watered" or check plot 34.5; and (4) "heavily watered" plot 53.7 acre inches of water. The above amounts include 1.4 acre inches of rainfall that fell during the growing season.

In the sprinkler plots, where 34.5 acre inches of water or more were applied during the growing season, the soil moisture determinations indicated an abundance and a good distribution of moisture in the first four feet. However, the per cent of soil moisture in the soils in the fifth and sixth foot level was not materially affected in the "lightly" or "light-medium" watered plots. On the other hand, the soils in the lower levels in the "heavily" irrigated plot with 53.7 acre inches water showed an increase in moisture content following each irriga-

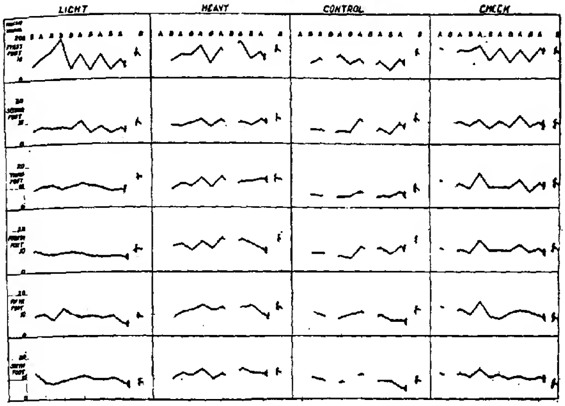

Figure 11. Chart showing the per cent of soil moisture before and after each irrigation at from 1 to 6 feet with different amounts of water. The plots were irrigated with ground sprinklers and from May 1 to Sept. 1 received acre inches of water as follows: (1) Light, 21.7; heavy, 53.7; control, 21.7; and check, 34.5.

tion. In the "lightly" and "light-medium" watered plots where less than 30 acre inches of water were applied, only slight increases in soil moisture were noted below the third foot following any irrigation. At no time during the season did the soil moisture in any of the plots reach the wilting point.

The soil moisture data in other tests carried on in 1931, (Fig. 12), indicated that, on the average for the different depths, there was little difference in moisture taken from the soil by the tree at distances of three, six, and 10 feet from the tree.

Influence of Varying Amounts of Irrigation Water on Growth of Trees, Size, and Color of Fruits. Studies were conducted during the season of 1931 on four six-tree plots of Jonathans in the experimental orchard near Wenatchee to determine what effect different amounts of irrigation water had on the growth, size, and color of fruit. The trees of the plots selected were very uniform in size, the trunk circumference in various plots averaging from 85.0 cm. to 91.3 cm. The water was applied with the long arm type of sprinkler under 35 pounds pressure, operated two feet from the ground, and the system used was classed as the under-tree method. The results of these tests are shown in Table 3.

The largest average terminal growth was made on the plot with the medium application of water, although all plots made good growth. The size of fruit varied in the different plots. The average pack per commercial box (42 lbs. net) for the heavily-irrigated plots was 119. The size was the same as the average for the lightly-irrigated plot. However, the fruit load on the lightly-irrigated plot averaged nearly

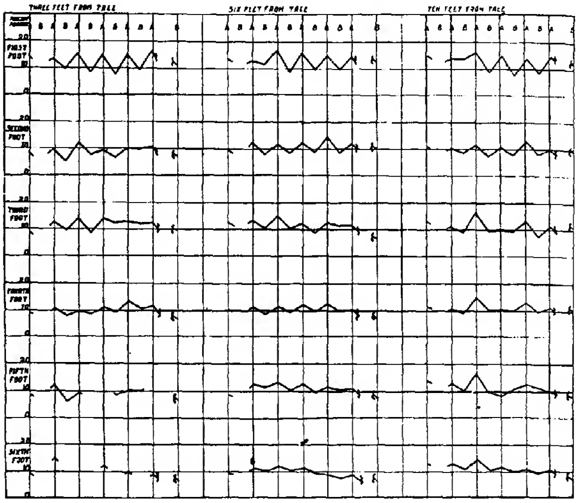

Figure 12. Chart showing the per cent of soil moisture before (A) and after (B) each irrigation from 1 to 6 feet in depth, 3, 6, and 10 feet from trees with the same amount of water applied with ground sprinkler.

500 less apples per tree, which probably accounts for the size of the individual fruits under the light irrigation. On the other hand, the heavily-irrigated plot produced over 200 boxes per acre more than the lightly-irrigated plot. The production of fruit in all plots averaged over 1000 boxes per acre.

The highest per cent "extra fancy" fruit and total red color was found on the "lightly" and "light-medium" watered plots. The color was a good bright red, not the dull brownish-red often exhibited by apples suffering from drought. The lower per cent "extra fancy" and total red color on the medium- and heavily-irrigated plots was essentially the same, considering the greater load of fruit. The trees in the "medium-irrigated"

Table 3. Tree Responses with Different Amounts of Water Applied by Ground Type of Sprinklers during Growing Season, 1931

Plot	Lightly	Light-medium control	Medium (Check)	Heavily
Acre inches water applied	21.7	25.9	34.5	53.7
Av. terminal growth inches	11.0	10.9	12.7	11.7
Av. No. fruits to 42 lb. box net	119.0	132.0	129.0	119.0
Av. total No. fruits per tree	2387.0	2774.0	2986.0	2880.0
Av. yield per acre boxes (52 trees)	1045.0	1097.0	1201.0	1263.0
Per cent "extra fancy" fruit	86.0	90.8	62.0	71.0
Per cent total red color	84.5	87.2	71.5	79.8

plot produced about 100 apples per tree more than the "heavily" irrigated plot. However, the color developed slower on the medium- and heavily-irrigated plots, and the fruit was less mature at harvest time than the fruit from the two plots with a lighter irrigation.

The results of these tests would indicate that tree and fruit response within certain limits of production are in agreement with the findings of Veihmeyer and Hendrickson (4): "Observations extending over a number of years in deciduous fruit orchards of California indicate that the soil moisture supply may fluctuate between wide limits without measurably affecting the growth of tree or yield and quality of fruits." However, the results shown in Table 3 indicate that the "light-medium" watered plot produced the highest quality fruit and would net the greatest returns to the grower considering the percentage "extra fancy" fruits and the additional cost of irrigation water.

Moisture Distribution. A comparison of the average moisture content of the first four feet of soil, 10 days after the irrigation season, obtained with the rill system and the sprinkler system of irrigation, as determined from composite samples, is given in Table 4. Previous to taking the soil moisture samples, the sprinkler plots had received a total of 21.6 acre inches and the rill plots a total of 38.7 acre inches of water

during the growing season. The results show a more uniform distribution of water over the entire soil area with sprinklers than with the rill system. The lowest point in water distribution of the rill system of irrigation is in the spaces in the tree rows parallel to the irrigation ditches.

Table 4. Comparison of the Soil Moisture Distribution between the Rill and Sprinkler Systems of Irrigation *

Rill-irrigated plots		Sprinkler-irrigated plots	
Location	Per cent of soil moisture	Location	Per cent of soil moisture
Tree row	6.31	Tree row	12.88
In ditch	14.57	In middle	16.75
Between ditches	12.33	Under tree	13.65
Average	11.07	Average	14.42

* These studies of moisture distribution were carried on in cooperation with George Sisler of American Fruit Growers in an orchard near Peshastin.

Cover Crops

Moisture present in the surface soil and applied at the proper time is an important factor in starting a cover crop in orchards. With the sprinkler method of irrigation, it is possible to provide the optimum moisture condition for starting a new crop. However, a new stand, once established with the roots six to 20 inches deep in the soil, seems to do equally well with a given supply of water whether it is applied by sprinkling or ditches. The irrigation furrows in the orchards are generally so far apart that the surface soil is not uniformly watered. Wide spaces between furrows commonly leave wide strips of soil too dry to start new plants. Table 4 shows the high percentage of moisture in the soil in tree rows with sprinkler irrigation as compared with adjoining plots with the rill system of irrigation. If the furrows are placed 15 to 20 inches apart and the irrigation carefully conducted, the soil is usually kept in good condition for seed germination and growth of young plants. After the cover crop is well established, there seems to be no difference in the development of the plants, whether water is applied by sprinkling or by rill irrigation.

Fruit and Tree Response

There was more vigorous growth of trees with sprinkling than with the furrow system of irrigation, as shown by the terminal growth and area of individual leaves. The fruits on the trees in the sprinkled

Table 5. Type of Irrigation and Amount of Water Applied during Season to Sprinkler Test Plots, and the Average Terminal Growth of the Trees

Plots	Type of irrigation	Number irrigations	Total hours watered	Average time per irrigation (hours)	Acre inches water per irrigation	Total acre inches water for season	Average terminal growth (inches)
(1) Jon. 1	Overhead sprinkler	9	121½	13½	4.1	37.0	8.29
Jon. 2	Overhead sprinkler	9	94½	10½	3.2	28.8	6.32
Jon. 3	Ground sprinkler	9	103½	11½	4.2	37.5	7.18
Jon. 4	Furrow-check	9	198	22	5.5	49.8	5.87
(2) K. D. 1	Overhead sprinkler	12	116	9⅔	2.5	30.4	
K. D. 2	Furrow-check	12	288	24	3.9	47.0	
(3) Del. 1	Overhead sprinkler	11	110	10	2.0	22.5	
Del. 2	Furrow-check	12	344	28⅔	3.2	38.8	

(1) Jon.—Jonathan plots, Experimental Orchard, Wenatchee.
(2) K. D.—King David plots, American Fruit Growers. King David Orchard, Wenatchee.
(3) Del.—Delicious plots, American Fruit Growers Orchard, Peshastin.

plots were larger but developed less color, the per cent of "extra fancy" grade was lower, and the maturity seemed to be delayed. The average pressure test of fruit from King David trees in the sprinkler plots was 17.8 pounds at harvest time and that from the furrow-irrigated trees 16.3 pounds. This delay in maturity apparently delayed color development of the fruit. The stimulation of growth noted with the initiation of sprinkling presumably may be attributed to the greater root activity in areas that previously were not adequately supplied with soil moisture. After the establishment of more uniform and stable conditions of root activity, it seems probable that the succeeding annual growths of the trees might become comparatively less.

In the plots where the studies were made, the water was measured in acre inches per plot by the use of meters. The amount of water applied to each plot is shown in Table 5. The furrow or rill-irrigated plots, which received from 12 to 17 acre inches more water than did the sprinkler plots, were used as check plots. There was some run-off and waste water from the check plots but none from the sprinkled plots. In two plots (Jon. 1 and 2) where overhead sprinklers were used, comparisons were made between a "moderate" application of water (37.0 acre inches), and a "light" application (28.8 acre inches).

Tree Growth. A comparison of tree growth under the different systems of irrigation was made by determining the average length of the terminal growth and the average size of the leaves. Twenty terminals with two or more years of previous growth shown were measured upon each tree 5 to 12 feet from the ground, around the perimeter of the tree. Only branches that were making an outward growth instead of upright type of growth were measured. The data showing the average terminal growth for the Jonathans, indicate that, even though more water was applied to the furrow-irrigation plot, the trees made the least terminal growth. The plot with the overhead sprinklers and "moderate" irrigation, or 37 acre inches of water, made the greatest growth, amounting to nearly two inches more than the same system with one-fourth less water. The overhead sprinkler trees made about one inch average better terminal growth than did the ground sprinkler trees with the same amount of water.

Figure 13 shows comparisons of terminal growth on the Jonathan, King David, and Delicious. The percentage increase of terminal growth of the trees of the overhead-sprinkler plot over the furrow plot for the Jonathan, King David, and Delicious was 40.7, 3.8, and 13.4, respectively. This was true, notwithstanding the fact that the varieties in the sprinkler plot in the order named received respectively 12.8, 16.6, and 16.3 acre inches less water per acre than where grown under furrow irrigation.

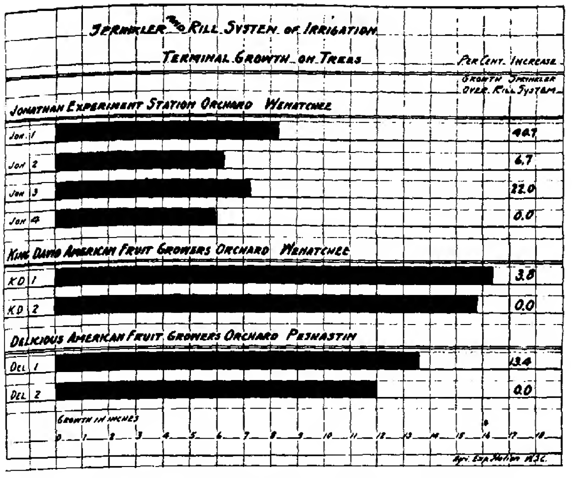

Figure 13. Comparisons of Terminal Growth of Trees in the Jonathan, King David, and Delicious plots by different methods of irrigation.

Size of Leaves. The leaf area was determined from a large number of leaves from each tree and plot. The leaves were selected from comparable positions on each branch. The results are shown in Figure 14. The leaf areas of ground sprinkler and check plot trees were nearly the same. The leaves on the trees of the overhead-sprinkler plot, with "light" application of water, were 5.6 per cent larger, and those of the overhead-sprinkler plot, with "moderate" application of water, were 18.5 per cent larger than were the leaves of trees in the furrow or check plots.

Size of Fruit. The size of fruit as affected by the system of irrigation was determined on the Jonathan plots by limiting the leaf area to 20 leaves per fruit. (Magness, Overley, and Luce, 3). The fruit was measured every two weeks during the growing season and the final measurement taken on September 15, just previous to harvest. The average increase in size of fruit as shown in Figure 14 was 372.1 per cent for the check; 418.1 per cent for the ground sprinklers with "moderate" irrigation; 423.6 per cent for the overhead sprinklers with "light" water application, and 435.0 per cent for the overhead sprinklers with "moderate" water application. The final growth obtained was repre-

sented by the average number of apples per standard box, which was as follows: 155 for check; 138 for ground sprinklers; 136 for overhead sprinklers, "light" irrigation; 132 for overhead sprinklers, "moderate" irrigation. Even though less water was applied in all the sprinkler plots, the fruit was larger than in the check plots where the leaf area was the same.

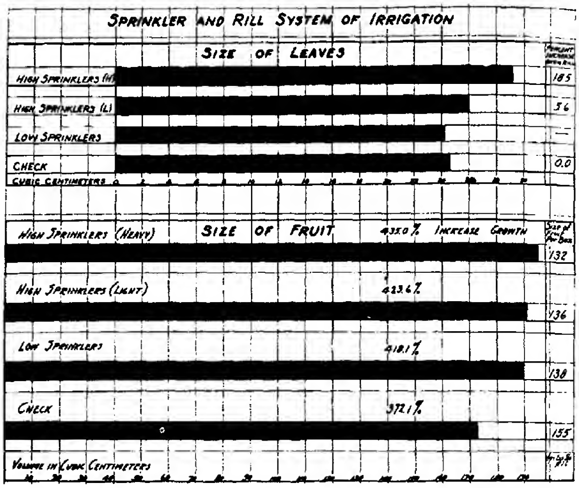

Figure 14. Comparisons of size of leaves and size of fruit from trees in the Jonathan plots by different methods of irrigation.

Color of Fruit. In tests with the Jonathan and King David, comparing sprinkling with furrow irrigation for the influence on color, the results in Figure 15 show less total color and less "extra fancy" fruit at harvest time from the sprinkler plots. These results confirm previous investigational work. Morris (unpublished data, 1924) found that the relative humidity of the atmosphere during the four weeks previous to harvest affected the degree of color development. A relative humidity of about 60 per cent permitted only about 25 per cent color development; a relative humidity of approximately 35 per cent permitted about 50 per cent color development. When the relative humidity was 15 per cent, approximately 68 per cent of the fruit sur-

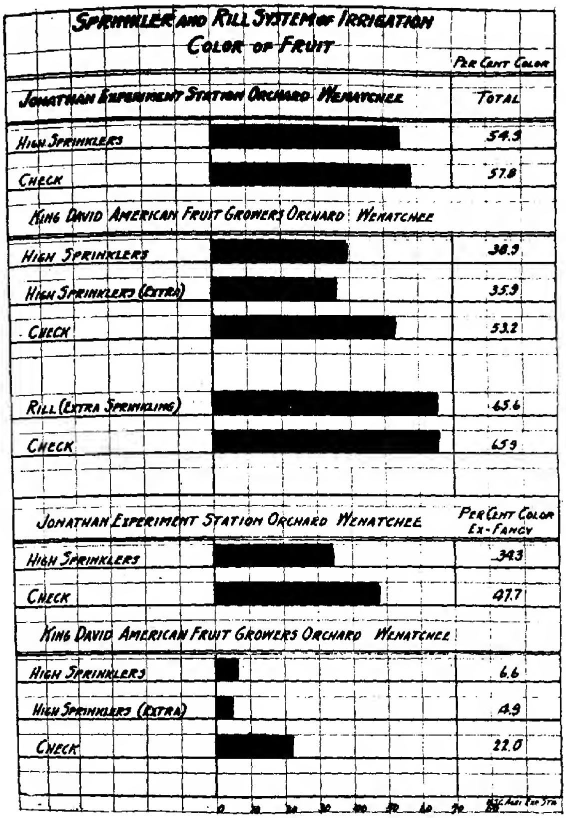

Figure 15. Comparisons of color of fruit from trees in the King David and Jonathan plots irrigated by different methods.

face was colored. Sprinkling short periods each night from September 9 to October 4 permitted color development on Jonathan of about 39 per cent. Sprinkling at intervals during the day from September 9

to October 4 permitted about 43 per cent color development. The check trees unsprinkled were about 65 per cent colored. These results are in agreement with those of Willis (5) who found that water sprayed continuously on apple trees dulled the color of the fruit.

A total of 23,829 apples were harvested from the Jonathan plots and 45,147 apples from the King David plots. Nearly equal amounts were harvested from each plot. Each apple was graded on the basis of color into classes as follows: 90-100 per cent; 70-90; 50-70; 30-50; 10-30; and 0-10. The results are shown in Figure 15.

The total average per cent color on the Jonathan apples from the overhead-sprinkler plots was 54.9, while that from the check plot was 57.8. The "extra fancy" fruit, as determined by color only, from the same plots was respectively 34.4 per cent and 47.7 per cent.

In the King David[1] plots with the regular sprinkling irrigation program, the average per cent of color on the fruit was 38.9 per cent, while in the check it was 53.2 per cent. Furthermore, the sprinkler plots receiving an additional sprinkling of one to two hours per night during the two weeks previous to harvest had a total color of only 35.9 per cent. In these same plots, the percentages of "extra fancy" fruit at harvest, as determined by color only, were as follows: for the check 22.0 per cent; for regular sprinkler plot 6.6 per cent; and, for sprinkler plot with additional preharvest sprinkling 4.9 per cent.

In another part of the King David orchard, where the fruit developed a higher color, several trees that had been irrigated by the furrow system throughout the season were sprinkled one to two hours per night for two weeks previous to harvest. The fruit from the sprinkled trees had 65.6 per cent color, and the fruit from the trees without additional sprinkling had 65.9 per cent color.

Orchard Insect Control as Affected by Sprinkling

A number of fruit growers have generally believed that irrigation of the orchards by applying the water with overhead type of sprinklers would aid in controlling the codling moth. This belief was based on the assumption that the application of water as rain would tend to lower temperatures and thus adversely affect the deposition of eggs by the codling moth. The use of water in this form was also thought to prevent by mechanical means the deposition of eggs and the entry of larvae by washing off the young larvae as soon as they hatched.

Since eggs are deposited by the moths over a long period of time, beneficial results by overhead sprinkling could not be expected unless the application of the water was more or less continuous for at

[1] The King David plots were located in the American Fruit Growers' orchard near Wenatchee.

least those periods of the day in which eggs are being deposited. Experimental tests where water was applied in this manner every evening did show some improvement in control over tests where the water was applied at intervals of a week or 10 days. However, in neither case did the control of the codling moth by spray applications equal that obtained in plots not sprinkled, although identical spray applications were given. (Fig. 16.)

The use of overhead sprinklers for irrigation at intervals of 10 days or two weeks did not prove to have any appreciable deterrent effect on codling moth egg deposition or on larval entry. On the other hand, it was found that overhead sprinkling actually interfered with spray control of this insect in that the water sprinkled on the tree actually removed a portion of lead arsenate deposited on the leaves and fruit. (Fig. 16.)

In these tests, three spray treatments were given to plots irrigated by the rill system and by overhead sprinklers, as follows: lead arsenate 3-100 used alone, lead arsenate 3-100 with spreader ½ pound to 100, and lead arsenate 2-100 plus mineral oil 1-100. The fruit on each of these plots was analyzed for arsenic before and after the sprinkling was done. These results showed that approximately 29 per cent of the lead arsenate was removed by each sprinkling. There were no significant differences in the amount of lead arsenate removed by sprinkling from any of the spray plots, even though oil was used in one of the combinations. In every case, the sprinkling was followed by a spray application except in July when no spray was applied.

The fruit check on all plots in this test showed that a reduction in deposit of lead arsenate was reflected in poorer worm control. In another series of tests where the sprinkling did not precede the spraying, but was applied as a general orchard practice without regard to the spray program, the lessened worm control was much more marked. In a third series of plots, where the trees were sprinkled about an hour very night during the latter part of August, the worm injury was not as great as with the plots receiving the normal sprinkling, but was greater than the plots where water was applied by the furrow-irrigation method.

In order to determine the effect of sprinkling irrigation on the various orchard insects in the district, eight different orchards where both methods of irrigation were practiced were observed during the season of 1930. The results indicated that the only insects that were affected to any extent by the sprinklers were the red spiders. In four of the sprinkled orchards, including the trees on the experimental orchard left unsprayed, no red spiders were found. In two other orchards only a light infestation was noticed, while in two orchards spider damage was seen and the owners reported applying an oil spray.

In all orchards under furrow irrigation red spider infestation varied from light to severe, and in most cases necessitated the use of oil sprays.

Aphis infestation was not severe in any of the orchards under observation, and was the same whether irrigated by sprinklers or by the furrow method.

Leaf hopper injury was marked in all the orchards observed and was not affected by the sprinklers.

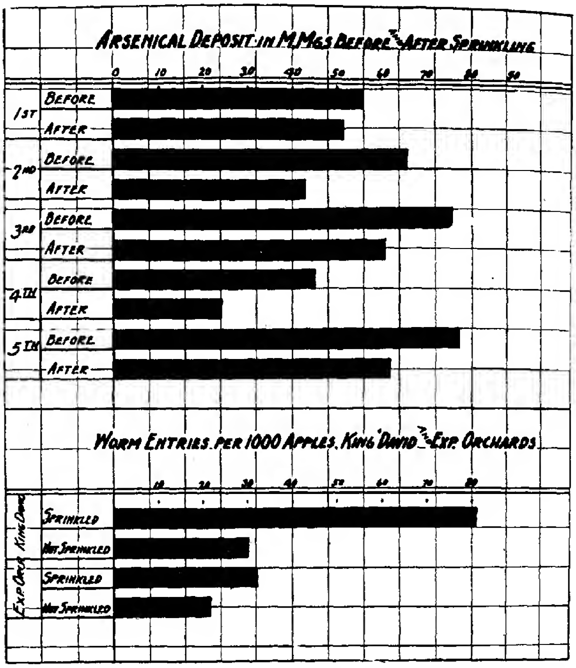

Figure 16. Average deposit in m.mg. arsenic per square inch before and after sprinkling and comparison of worm entries in fruit from sprinkled and furrow irrigated plots.

The Effect of Sprinkler Irrigation Upon Arsenical Spray Residue on Apples

The experience of investigators and orchardists in eastern fruit-growing districts, where rains are generally more frequent and copious than in the irrigated sections of the Northwest, has indicated that there may be a weathering effect on the arsenical deposits on the trees as a result of this rainfall, particularly when maintained steadily over a considerable period of time. The use of sprinkler irrigation in the Northwest, therefore, naturally gave rise to questions concerning the effect of such irrigation upon residue removal from the fruit at harvest time.

Fruit at harvest time was selected from definite locations in the trees and the lots were analyzed separately to give a picture of the residue load. This method permitted only an evaluation of the results as they were obtained at picking time. Obviously, it gave no inkling as to the relative significance of the date of spraying and the date of sprinkler irrigations in effecting changes in residue, nor did it indicate the importance of environmental factors prevailing during each sprinkler application.

The results, however, of the analyses of Jonathan and Winesap apples[2], which are given in Tables 6 and 7, have seemed adequate to report. Some of the facts pertinent to the history of this fruit are dealt with in other sections of this bulletin and are not repeated here.

Observations in the field and the results presented in Tables 6 and 7 indicate that there was a distinct reduction in the average load of spray residue on fruit taken from trees in sprinkler plots, apparently as a weathering effect from the direct application of water by the

Table 6. Average Analyses of Uncleaned Jonathan Apples Taken from Trees in the Washington State College Sprinkler Plots

Irrigation method	Spray applied[1]	Grains arsenic trioxide per pound of fruit
Furrow	Lead arsenate	.073
Furrow	Lead arsenate-oil	.098
Ground sprinklers	Lead arsenate	.076
Overhead sprinklers	Lead arsenate	.051
Overhead sprinklers	Lead arsenate-oil	.063

[1] The lead arsenate spray was applied six times, 3 pounds to 100 gallons; the combination sprays six times, lead arsenate 2 pounds to 100 gallons and ¾% medium mineral oil (viscosity 70 seconds Saybolt.)

[2] Made by J. E. Fahey, U. S. Bureau of Chemistry and Soils, Wenatchee, Wash.

Table 7. Average Analyses of Uncleaned Winesap Apples Taken from Different Parts of Trees in the Washington State College Sprinkler Plots[1]

Plots	Position of samples: Portion in tree	Position of samples: Height in tree	Grains arsenic trioxide per pound of fruit
Furrow irrigation	Outside	0- 6 ft.	.085
		6-12 ft.	.076
		12-18 ft.	.063
	Inside	0- 6 ft.	.111
		6-12 ft.	.097
		12-18 ft.	.063[2]
Ground sprinklers	Outside	0- 6 ft.	.038
		6-12 ft.	.058
Overhead sprinkler tree in center of area covered by four sprinklers	Outside	0- 6 ft.	.067
		6-12 ft.	.051
		12-18 ft.	.049
	Inside	0- 6 ft.	.083
		6-12 ft.	.054
		12-18 ft.	.049[2]
Overhead sprinkler in tree	Outside	0- 6 ft	.057
		6-12 ft.	.056
		12-18 ft.	.055
	Inside	0- 6 ft.	.074
		6-12 ft.	.083
		8-12 ft.	.044

[1] The fruit had six cover sprays of lead arsenate, 3 pounds to 100 gallons.
[2] The two locations, inside and outside, essentially coincided in these cases.

overhead sprinklers. The percentage of this reduction, amounting to from 30 to 35, was about the same for fruit sprayed with lead arsenate as for that to which combination sprays of oil and lead arsenate had been applied. This reduction in residue load may have occurred as a result of the inherent weathering effect of the water itself or from a combination of the solvent action of alkaline dust on the fruit and liquid run-off as sprinkling continued.

There was little or no apparent reduction of residue load on fruit when the average analyses for entire furrow-irrigated trees were com-

pared with those in the ground sprinkler plots. A determination of the residue load on fruit in different parts of the tree, however, indicated that, while there was naturally little or no effect from such sprinkling in the upper portion of the tree, there was a marked effect on the residue load found on apples in the lower portion adjacent to the ground sprinklers. Within the range zero to six feet from the ground, the reduction amounted to as much as 50 per cent when compared with the load upon fruit from a similar position in a tree without sprinkler irrigation.

Apparently on account of the uneven distribution of water from the overhead sprinklers, there was a variable reduction in residue load on fruit from various parts of a tree, whether the tree stood in the center of an area covered by several sprinklers or whether it was directly beneath a sprinkler. This variable character was undoubtedly also related to the shape of the individual tree and to the type of foliage growth. This relation suggested that there may be more variable residue deposits in different parts of a sprinkled tree than in one under furrow irrigation, even when the spraying approached the ideal of uniformity of application and thoroughness.

There was a greater spray residue load on fruit taken from the interior of the tree form, particularly in the lower levels, suggesting (1) that the run-off and drip accumulated on such fruit to a greater degree and built up the deposit, and (2) that the fruit in the interior may have had spray material applied to it from a greater number of angles, with a resulting better coverage.

Relation of Type of Irrigation to Apple and Pear Diseases

Analysis of the various factors contributing to the distribution of many fruit diseases indicates that atmospheric humidity is of primary importance. In the principal apple-growing sections of the Pacific Northwest, when usual orchard practices are followed, many diseases rather common elsewhere are of slight economic consequence. This is probably due to environmental factors, such as intense sunlight and low relative humidities that are common to these districts and that are detrimental to the growth and development of the disease organisms.

With the introduction of any new orchard practice, especially one that may affect or change any of the environmental factors mentioned, the importance of a careful examination for disease invasion needs little emphasis. During the growing season of 1930, observations were made of the effects of sprinkler irrigation, as compared with the furrow or rill system, on the occurrence and behavior of some tree and fruit diseases of apples and pears in the Wenatchee Valley.

Powdery Mildew (Podosphaera leucotricha). Studies on powdery mildew under the various irrigation methods were conducted on a

block of 90 Jonathan apple trees at Peshastin, Washington. During the growing season of 1929 these trees carried a heavy infection of mildew, and examination in the spring of 1930 indicated that a high percentage of these buds and twigs carried over-wintering mycelium.

The block was divided into three plots of 30 trees each. Plot 1 was irrigated by overhead rotating sprinklers. In plot 2 the ground type or common lawn sprinkler was employed. Plot 3 was used as a check plot and was irrigated by the rill or furrow system.

Observations made during the early summer showed definitely a heavier leaf and terminal infection occurring in the overhead-sprinkler plot than in either the ground-sprinkler or furrow plots. No significant differences could be found between the two last-named plots.

At the time of harvest more than 15,000 fruits, under the different systems of irrigation, were individually checked for powdery mildew markings. Results in percentage of disease-marked fruit were as follows:

Rill or furrow system	22.5
Ground sprinklers	25.5
Overhead sprinklers	10.6

In general, there were more than twice as many mildew-marked apples in the ground-sprinkled and rill systems as in the overhead-sprinkled plot. The fact that the overhead-sprinkler plot had the highest initial foliage and shoot infection is interesting. It is possible that under the overhead-sprinklers an actual mechanical removal or washing of the spores from the comparatively smooth surface of the apple takes place, whereas in the case of leaf and terminal infections the spores are probably better established and protected, especially those on the under side of the leaves.

Perennial Canker (Gloeosporium perennans). It has been rather definitely shown by Fisher and Reeves (1) that rainfall is the primary carrier for tree and fruit infection of perennial canker. Wounds made in the bark in the fall or winter and located so as to receive rain water that has washed existing cankers have been found to become infected. The resulting cankers complete their seasonal growth and mature spores the following spring. Fruit rot was also found to be more prevalent on apples grown under cankers than on those produced in the tops of the trees. Also, if boxes of apples from non-cankered trees were permitted to stand beneath cankered trees during periods of rainfall, the fruits showed a high percentage of rots after subsequent storage.

Since the evidence shows rather definitely that tree and fruit infections are caused primarily by water-borne spores, the use of overhead-sprinkling systems of irrigation on cankered trees becomes a

subject for investigation. For this purpose, a block of 20 uniformly badly-cankered Esopus Spitzenburg trees were selected. Overhead-sprinklers were set over one-half of the trees while the remaining half was irrigated by the furrow system. One sprinkler head was set for each tree and the area covered by each sprinkler was approximately 25 feet in diameter.

The dates of sprinkling and amounts of water applied per tree were as follows:

August 18	250 gallons
August 28	400 gallons
September 13	250 gallons
October 2	400 gallons

Natural precipitation occurring during this period was:

September 8	0.17 inches
September 15	0.04 inches
September 29	0.03 inches

Effect of Sprinkling on Spore Development. The acervuli or spore-bearing bodies of the fungus, which are scattered over the surface of the canker, are formed beneath the epidermal layer of bark and later become erumpent. Spores from these pustules are not readily disseminated while the spore pads are dry. However, in the presence of moisture, these spore masses become gelatinous and the spores are readily carried by rain water to parts of the tree or fruits beneath, where they may become established and cause infection.

In the present experiment, it was found that many acervuli became gelatinous about three weeks earlier in the sprinkled plots than in the check or furrow-irrigated trees. Because of a number of factors that influence canker infection, it is rather difficult to obtain accurate data as to the effect of sprinkling on the production of new cankers, although possibilities for the earlier dissemination of spores in the sprinkled plots might be indicative of greater potential infection.

Effect of Overhead Sprinkling on Perennial Canker Fruit Rot. Fisher and Reeves (1) report a marked reduction in perennial canker fruit rot when a 4-4-50 Bordeaux mixture spray is applied prior to fruit harvest.

In the present investigation, information was desired on the following points: (1) the effect of overhead-sprinkling on the development of perennial canker fruit rot, and (2) the effect on the spray deposit, and efficiency in control of the rot by Bordeaux mixture and ammoniacal copper carbonate.

The sprinkled and unsprinkled blocks of cankered trees were further divided into three plots. One portion was sprayed with Bordeaux mixture, another with ammoniacal copper carbonate, and the un-

sprayed trees left as checks. The sprays were applied September 15 and at the following strengths:

Bordeaux mixture:	Ammoniacal copper carbonate:
2 lbs. copper sulphate	5 oz. copper carbonate
2 lbs. lump lime	3 pints ammonia (26° Baume)
50 gals. water	60 gals. water

The fruit was picked and packed without cleaning from October 3 to October 6, and immediately placed in a cold storage room operated at an average temperature of 31° to 32° F. A careful selection of fruit was made during harvest so that one lot was picked from a position on the tree where it would most likely receive a drip from tree cankers during a rain or sprinkling period. Another lot was picked from the tops of the same trees, and still another lot, referred to as "tree run fruit," was selected as the average for the entire tree.

The fruit was removed from cold storage from April 6 to April 9 and each apple checked for canker rots. After this first examination the unaffected fruits were re-wrapped and held in common storage at an average temperature of 55° F. for three weeks. At the end of this time they were again examined for further canker rot development. The percentages of perennial canker rots found on fruits under the various treatments for both examinations are given in Table 8.

The results obtained indicate that overhead sprinkling materially increased the development of perennial canker fruit rot. In the "tree run" fruit and in fruit selected from beneath cankers, the percentage of fruit rot was appreciably reduced with Bordeaux mixture and ammoniacal copper carbonate sprays, although the latter spray was less effective than the Bordeaux mixture. The effect of both sprays in controlling the rot was materially reduced by sprinkling. Very little infection was found on apples picked from the tops of the trees, but, here again, the sprayed fruits showed a lower rot percentage than the unsprayed.

The reduced effectiveness of the sprays under sprinklers can probably be attributed to an actual washing off of the copper sprays. Chemical analysis of fruits at harvest time substantiated this possibility, since there was more copper on the fruit from furrow-irrigated trees than from sprinkled trees.

Pear Blight (Bacillus amylovorous.) Although pear blight occurs but rarely in the Wenatchee district, considerable infection was found during the summer of 1930 in a pear orchard irrigated with overhead sprinklers. The disease was first observed on July 28 and was actively progressing. At this time some of the new shoots were being attacked; the leaves were wilted, but had not reached the stage of discoloration. This

Table 8. Percentage of Perennial Canker Rots on Esopus Spitzenburg Apples Under the Furrow and Overhead Sprinkler Systems of Irrigation and with Two Types of Control Spray. Held in Cold Storage from October 4, 1930, to April 6, 1931, and in Common Storage until April 28, 1931

Number apples	Location on tree	Irrigation	Spray	Per cent of decay		Total per cent rots for the two examinations
				End of cold storage period	3 weeks out of storage	
581	Under canker	Furrow	None (check)	2.92	9.98	12.90
401	Under canker	Furrow	Bordeaux mixture	.50	2.24	2.74
389	Under canker	Furrow	Amm. copper carb.	.51	6.17	6.68
546	Under canker	Sprinkler	None (check)	10.07	10.99	21.06
376	Under canker	Sprinkler	Bordeaux mixture	2.65	6.65	9.30
376	Under canker	Sprinkler	Amm. copper carb.	1.86	10.90	12.76
368	"Tree run"	Sprinkler	None (check)	3.00	7.87	10.87
178	"Tree run"	Sprinkler	Bordeaux mixture	.56	3.94	4.50
185	"Tree run"	Sprinkler	Amm. copper carb.	2.16	7.02	9.18
268	Tops	Furrow	None (check)	.37	2.63	3.00
301	Tops	Furrow	Bordeaux mixture	.00	1.32	1.32
276	Tops	Furrow	Amm. copper carb.	.00	.72	.72
376	Tops	Sprinkler	None (check)	.53	1.86	2.39
289	Tops	Sprinkler	Bordeaux mixture	.34	1.04	1.38
288	Tops	Sprinkler	Amm. copper carb.	.00	1.04	1.04

condition indicates that the blight was not only developing in the initially infected branches but was also spreading to other terminals as well. The sprinklers were discontinued at this time and on August 6 the blight activity had apparently ceased, but whether this was merely a coincidence or resulted from the change of irrigation practice was not determined.

Downy Mildew (Phytophthora cactorum). During the latter part of July, 1930, in the Wenatchee district, a peculiar rot occurred on Bartlett pears. An inspection of the orchard where this disease was found revealed a large number of fruits actually rotting on the trees. These trees were about seven years of age and were irrigated by overhead rotating sprinklers. A dense crop of alfalfa covered the ground. About two bushels of infected fruits were removed from the one and a half acre orchard at this time.

Microscopic examination of the diseased tissues disclosed the interesting information that the pears were infected with a fungous organism of the genus *Phytophthora*. This diagnosis was further confirmed by submitting cultures and diseased fruit specimens to Washington, D. C., where the organism was found to be *Phytophthora cactorum*, a parasite capable of affecting various species of plants.

The occurrence of this disease on pears and apples is rather rare, particularly during the growing season, and it has heretofore been confined primarily to localities of high relative humidities, or found as a disease in storage. There seems to be no record of this disease ever occurring on pears in the orchard in any of the arid or semi-arid fruit-growing regions of the Pacific Northwest prior to this time.

The parasitism of the organism was demonstrated at harvest time by picking fruit hanging directly beneath infected pears which were most likely to receive the drip from the overhead sprinklers. After three months in cold storage, 60 per cent of the fruit, which appeared sound at harvest, had developed the disease.

Results of spraying experiments indicated that the Phytophthora spores were very sensitive to the toxic action of copper sprays in the form of Bordeaux mixture 2-2-50 or ammoniacal copper carbonate and that the disease could be reduced by their use. However, more complete control was obtained with these sprays on trees where the overhead sprinklers were discontinued.

SUMMARY

1. A description, method of operation, advantages, and disadvantages are given of three classes of sprinklers, i. e., gear driven, reaction, and stationary head. The reaction type of sprinkler has been found to be the most efficient for orchard irrigation.

2. A discussion of the operating characteristics of sprinklers is presented under the following headings: (a) capacities; (b) trajectory; (c) uniformity of coverage; (d) pressure; (e) pipe friction; and (f) elevation.

3. The factors that determine the amount of evaporation between the sprinklers and the ground are wind, relative humidity, and temperatures of irrigation water and of the air.

4. The percentage of water evaporated from sprinklers throwing a fine mist was no greater than from those throwing relatively large droplets of water. Small droplets, however, are more easily carried away by the wind.

5. Several methods are used throughout the state for measuring water and a variety of units are employed with these methods. A comparison is made of the commonly used units.

6. The equipment required for sprinkler systems of irrigation is discussed under the following topics: (a) piping; (b) pump; (c) settling box; and (d) sprinklers.

7. Directions are given for the installation of orchard sprinkler systems. No one system is satisfactory for all orchards.

8. The pump of stationary spray plants is designed for pumping comparatively small quantities of liquids against high pressure, and, therefore, is not generally satisfactory for pumping irrigation water.

9. Ordinary stationary spray system pipes are small and offer excessive resistance to the flow of large quantities of irrigation water.

10. By using light, welded steel tubing and movable sprinklers, the cost of installation may be as low as $40.00 per acre when pumping equipment is not required. The cost, depending upon elaborateness, may be as high as $350.00 per acre.

11. The utilization by the trees of plant nutrients in the surface soils is favored by sprinkling.

12. Sprinklers make it possible to apply water more uniformly over areas to be irrigated, regardless of soil type or degree of slope of land. On bare soil, however, when sprinkler water is applied faster

than the soil can readily absorb, puddling or washing of the soil may result.

13. When properly applied without waste, 30 to 36 acre inches of water are generally sufficient to keep the main root zone of the soil supplied during the growing season.

14. Since the sprinkler system wets the surface soil uniformly, it provides excellent moisture conditions for germination and initial growth of a new cover crop.

15. Trees in sprinkler plots during the experimental period made greater terminal growth and tended to produce larger-sized leaves and fruits, notwithstanding the fact that less water was applied, than did trees irrigated by the furrow system.

16. The average amount and intensity of the color of the fruit was lessened and the maturity was slightly delayed by the use of sprinklers as compared with rill-irrigated trees.

17. The overhead sprinkling has no value in codling moth control, but instead interferes with the proper control by spraying methods. On an average, 29 per cent of the previously applied arsenate of lead load on apples was removed with each overhead sprinkling.

18. Aphis infestation and leaf hopper injury were not affected by sprinkling.

19. Overhead sprinkling, however, seemed to aid in the control of red spiders.

20. There was a reduction in the average load of spray residue on mature fruit harvested from trees irrigated by overhead sprinklers amounting to from 30 to 35 per cent, when compared with trees irrigated under the rill system.

21. With ground sprinklers, the reduction was on fruit within six feet of the ground, and amounted to as much as 50 per cent. The reduction apparently resulted from the "weathering" or the solvent effect of the water sprinkled on the fruit.

22. There was a greater spray residue load on fruit from the lower levels of trees with overhead sprinklers, possibly because of the run-off and drip that accumulated or the better initial coverage received.

23. The percentage of powdery mildew markings on Jonathan apples at harvest time from trees irrigated by overhead sprinklers was one-half that on fruits irrigated by ground sprinklers or with furrows, possibly because the overhead application of water washed off the spores from the surface of the fruit. There was, however, more terminal leaf infection in the overhead sprinkler plots.

24. In trees irrigated by overhead sprinklers, there is a possibility for the earlier dissemination of perennial canker spores as compared with furrow-irrigated trees. This might be indicative of greater potential infection.

25. Overhead sprinkling materially increased the development of perennial canker fruit rot.

26. The percentage of fruit rot was appreciably reduced with Bordeaux mixture and ammoniacal copper carbonate sprays, although the latter spray was less effective than the Bordeaux mixture.

27. The effectiveness of the sprays under sprinklers was reduced by the washing off of the copper sprays.

28. Pear blight was found to be more active later in the season in orchards with overhead sprinklers than in orchards irrigated by furrows.

29. Downy mildew (*Phytophthora cactorum*), normally a rare disease in the Wenatchee district, was prevalent in pear orchards irrigated by overhead sprinklers.

30. The downy mildew was reduced by copper sprays, but more complete control was obtained when the overhead sprinklers were discontinued.

31. Since conditions appear to be more favorable for the development of certain diseases by the use of overhead sprinklers, it is possible that their continued use over a period of years might produce serious conditions.

32. The ground sprinklers appeared to have fewer disadvantages than did the overhead sprinklers. The former required less pressure and did not wash off so much spray material. Furthermore, they did not favor certain diseases as much as did overhead sprinklers.

33. Ground sprinklers, however, required additional piping and equipment to irrigate an equal area as compared with overhead sprinklers.

34. The sprinklers seemed most likely to be economically successful on light, sandy, hillside soils where the natural head of water was sufficient to avoid the use of booster pumps.

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